

BAYES, MICROPHYSICS, AND POLARIMETRIC RADAR OBSERVATIONS

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GISS Lunch Seminar
March 1 2017

TRACKING UPDRAFTS USING POLARIMETRIC RADAR

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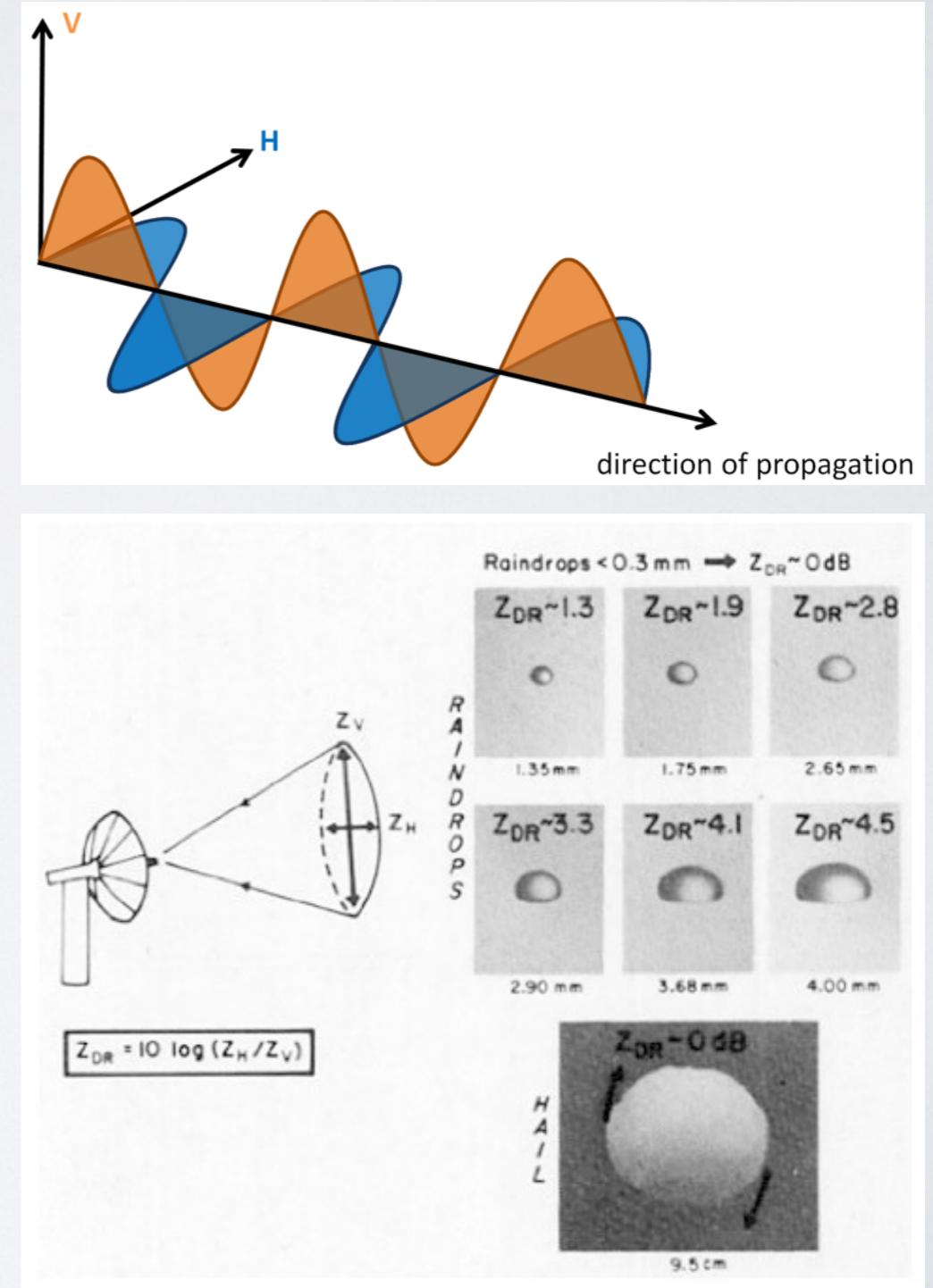
Abstract Stony Brook University, Stony Brook, NY, USA

THE BIG PICTURE

- There are large gaps in our understanding of atmospheric processes
 - Cloud microphysics is a prime offender
- Our models have limited fidelity
- We have lots of observations, but do we use them well?
 - e.g. do we respect their uncertainties?
 - e.g. do we fully utilize their information content?

POLARIMETRIC RADARS

- Polarimetric radars transmit/receive in multiple polarizations
- Polarimetric radar variables:
 - Z_{DR} : differential reflectivity
 - K_{DP} : specific differential phase shift
 - ρ_{HV} : co-polar correlation coefficient
- Plus, plain ol' vanilla radar reflectivity

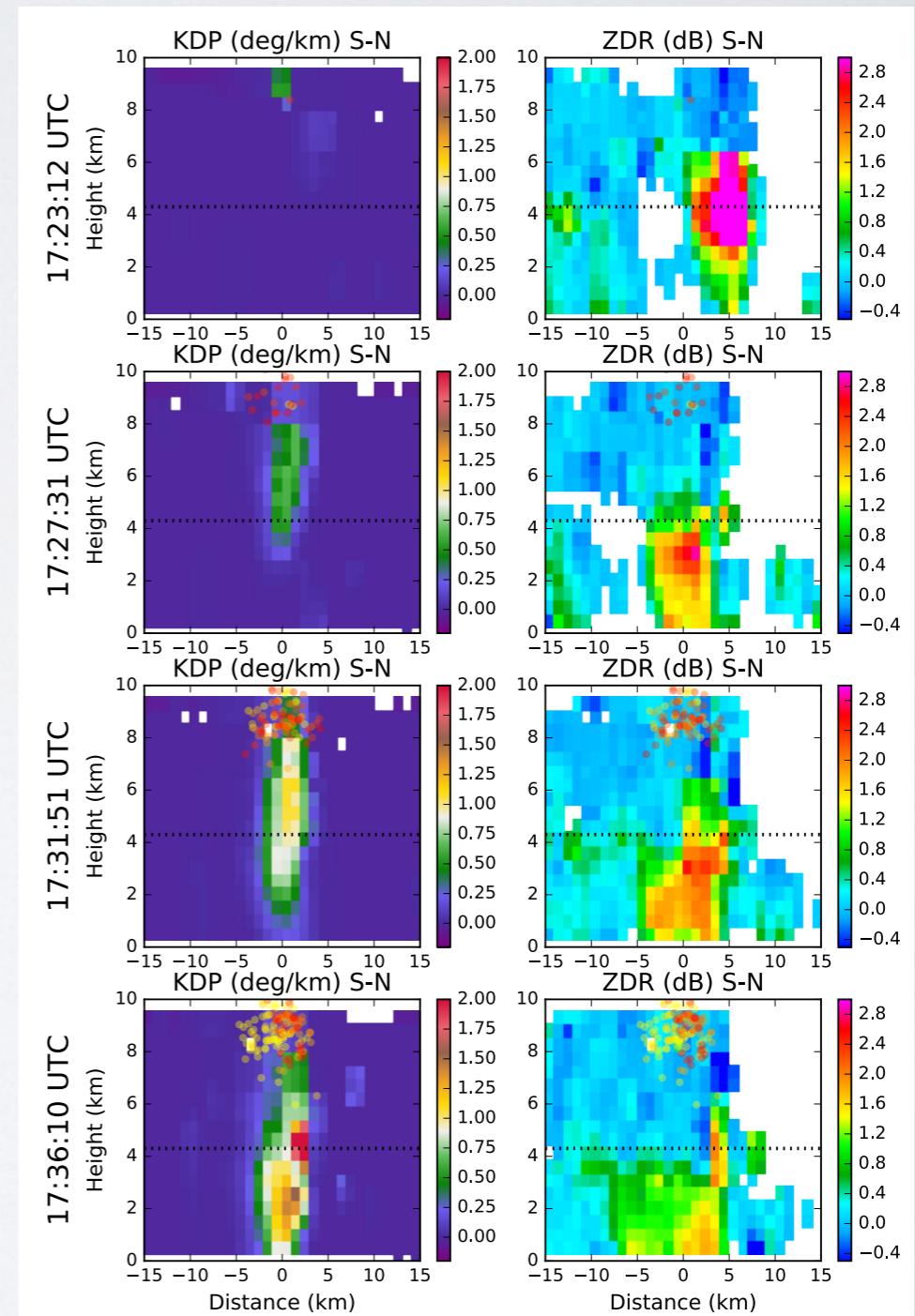


KDP AND LIGHTNING

- An example of how KDP and lightning activity correlate in space/time
- Lightning & KDP columns, Oklahoma May 20 2011

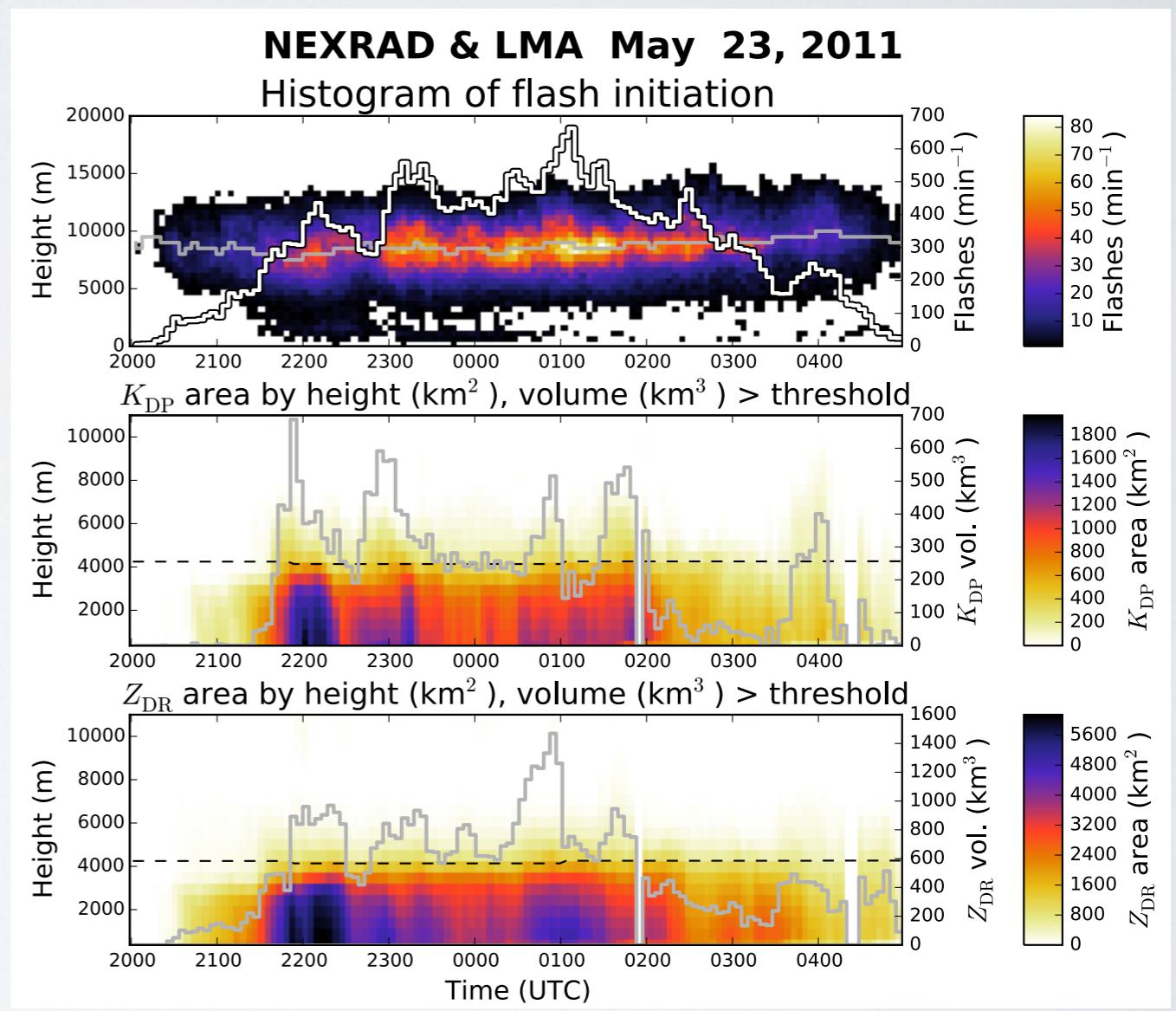
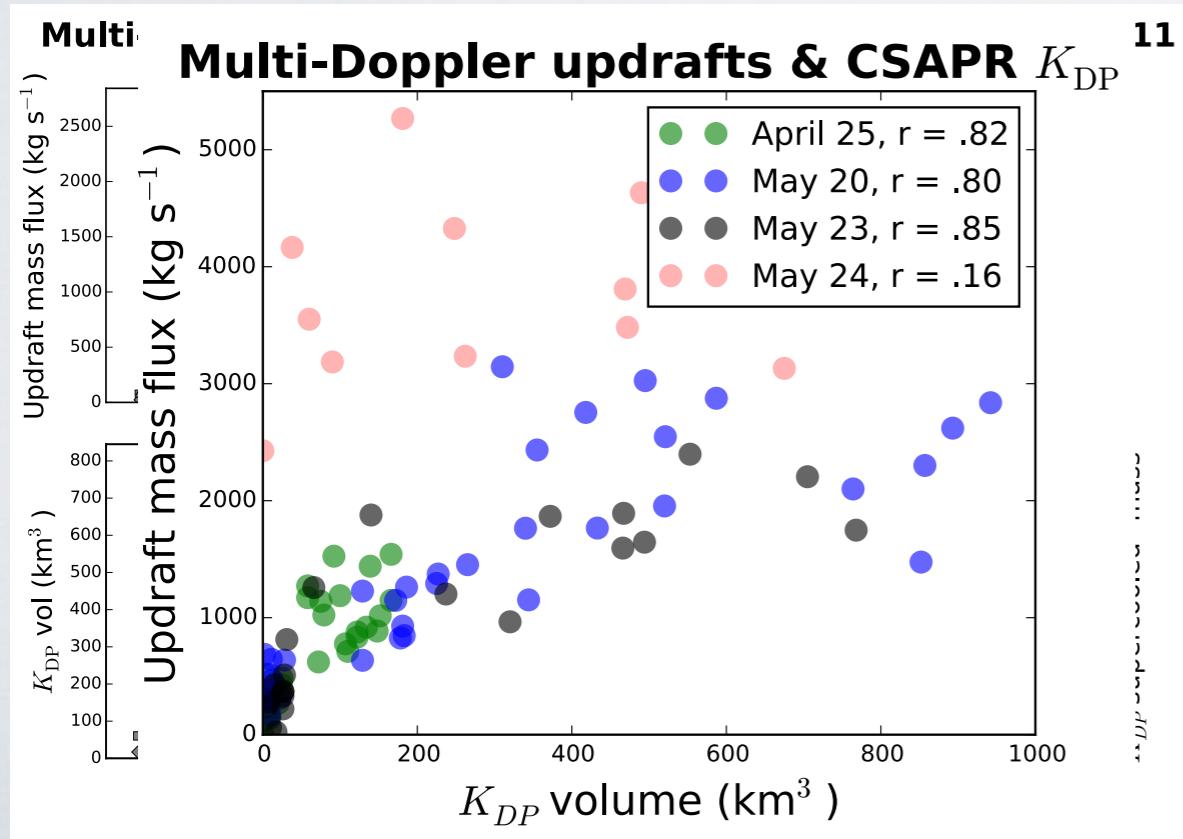
CONVECTIVE UPDRAFTS: KDP COLUMNS

- Typically, ZDR columns show up first (recirculated drops in nascent updraft)
- KDP columns show up next indicating substantial rain or liquid-coated hail mass
- Lightning peaks then shortly thereafter (mixed-phase microphysics of mature updraft)



KDP COLUMNS

- KDP columns correlate with updraft mass flux
- KDP and ZDR correlate with lightning

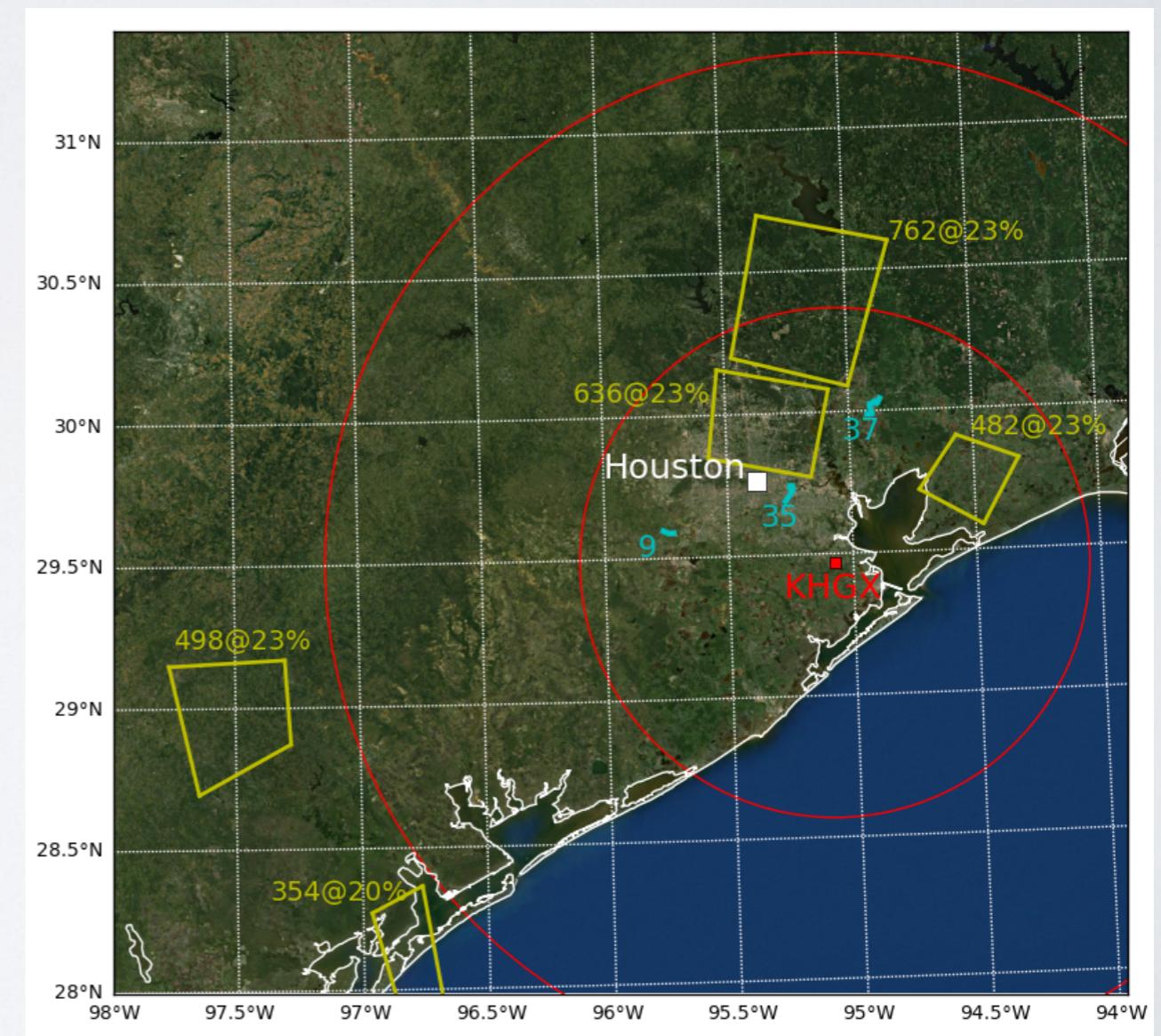


PROBLEMS WITH PREVIOUS KDP COLUMN ANALYSIS

- Bulk analysis over a wide field
 - Multiple updrafts at various points in lifecycle
 - Difficult to separate, say, aerosol effects from other meteorological effects on deep convection
 - an alternative: track a updraft cell in time

EFFECTS OF AEROSOLS ON CONVECTION: HOUSTON

- Houston TX NEXRAD radar (KHGX)
- Houston TX Lightning Mapping Array
- Satellite analysis of CCN (courtesy D. Rosenfeld)
- June 08 2013

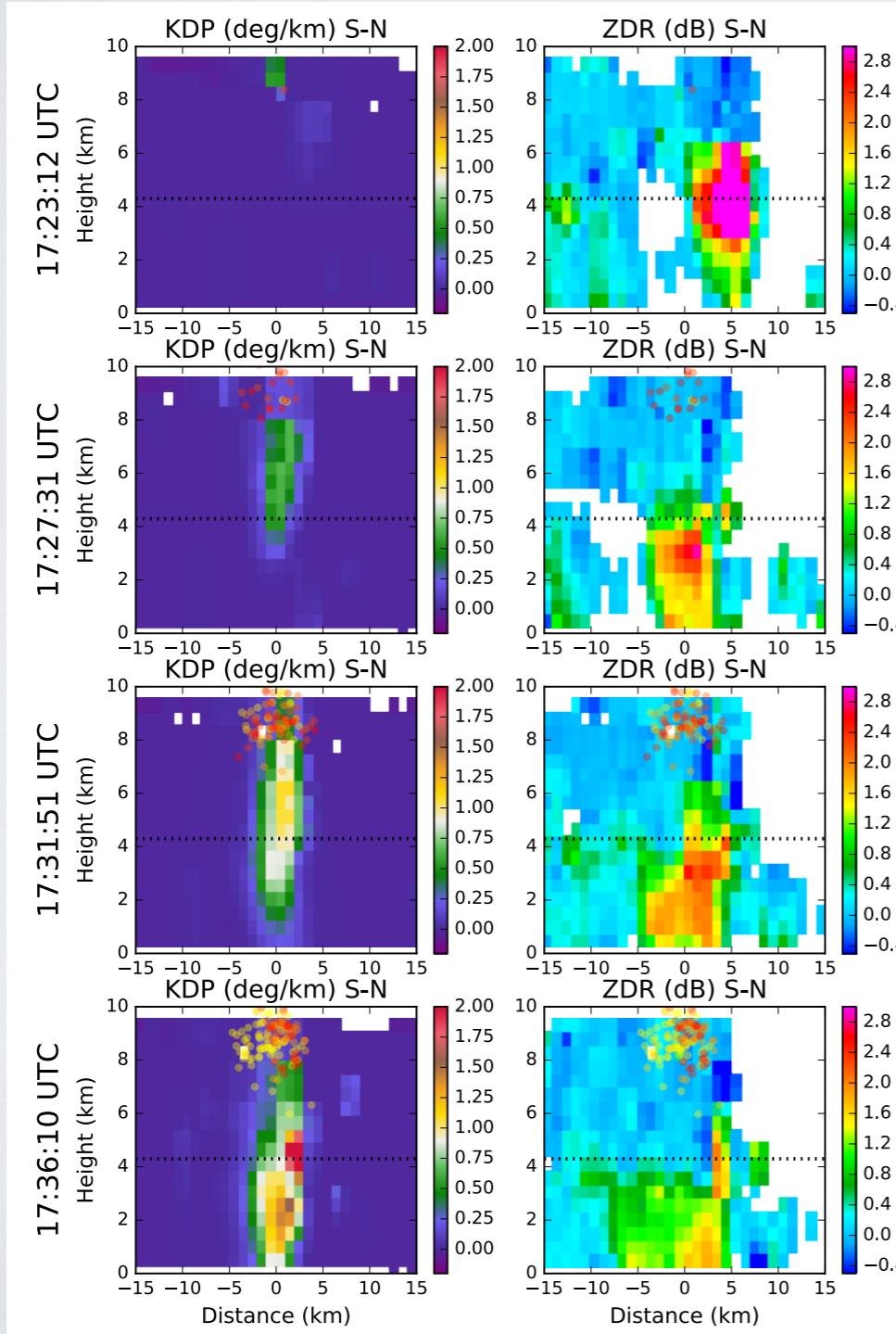


TRACKING

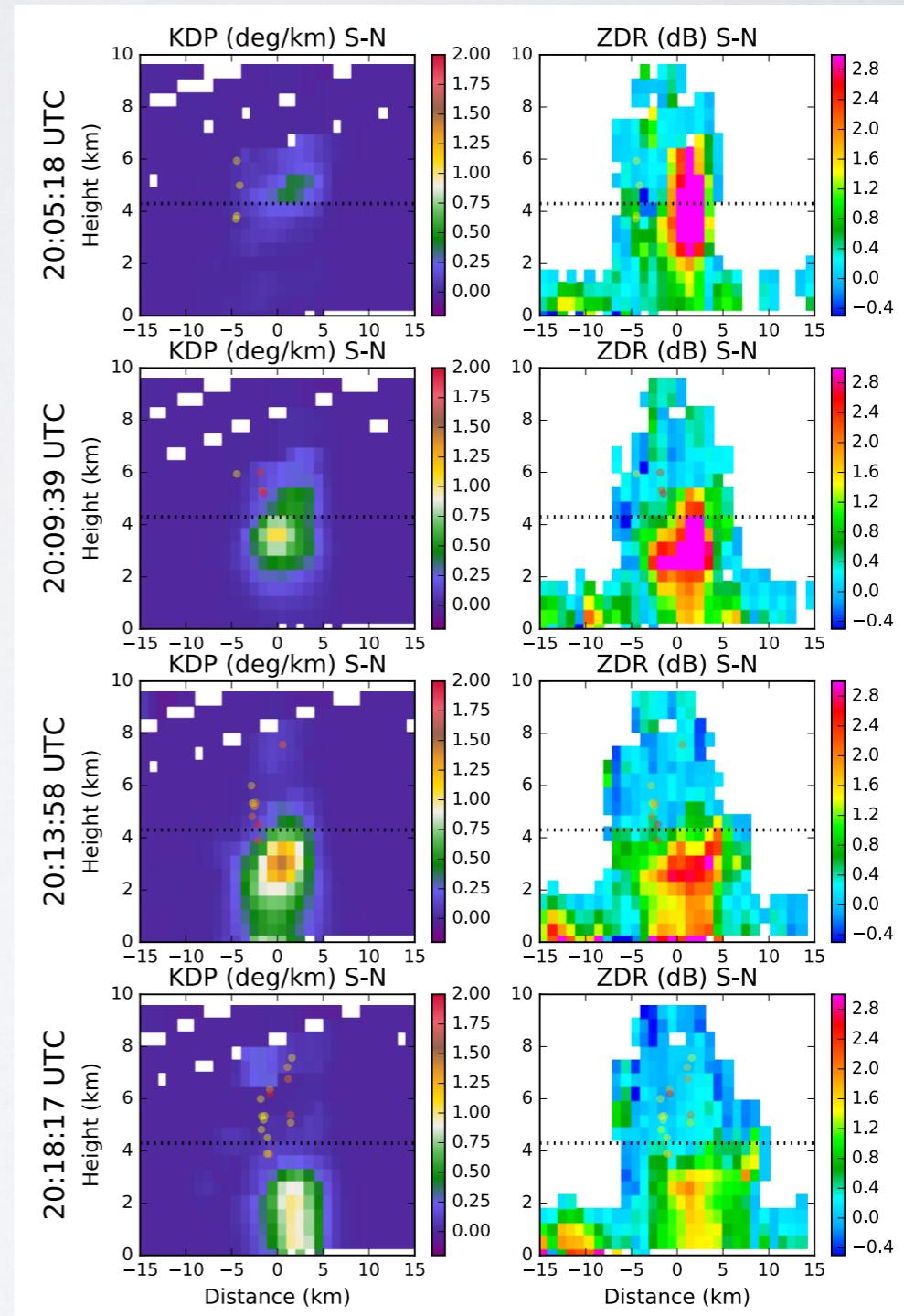
- Multiply KDP by height above melting level, integrate in slab
- Track in time using freely available software (TrackPy)
- Analyze radar, lightning and DSD retrievals
- Three examples:
 - Column no. 9
 - Column no. 35
 - Column no. 37

SUGGESTIVE CONTRASTS

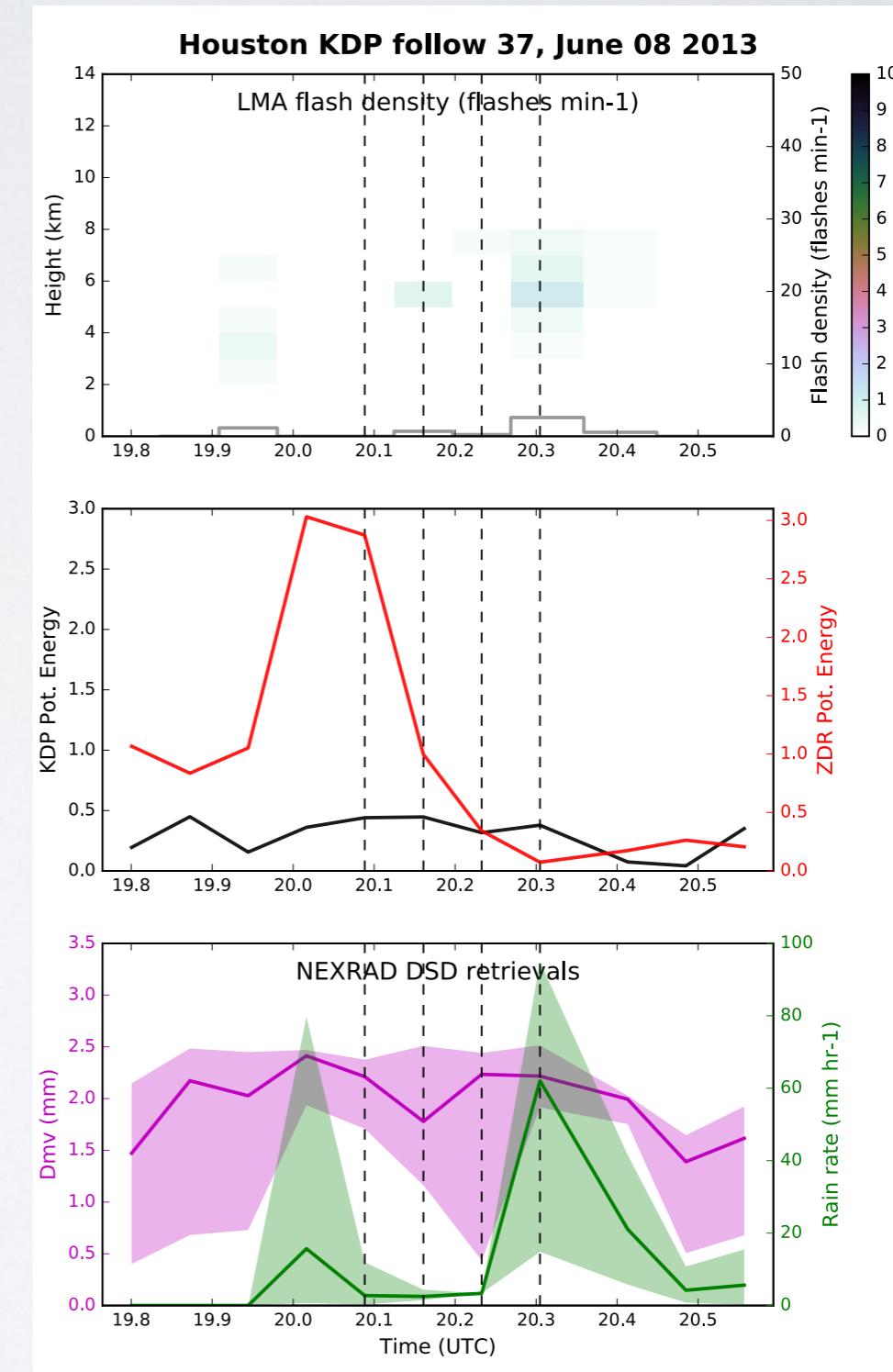
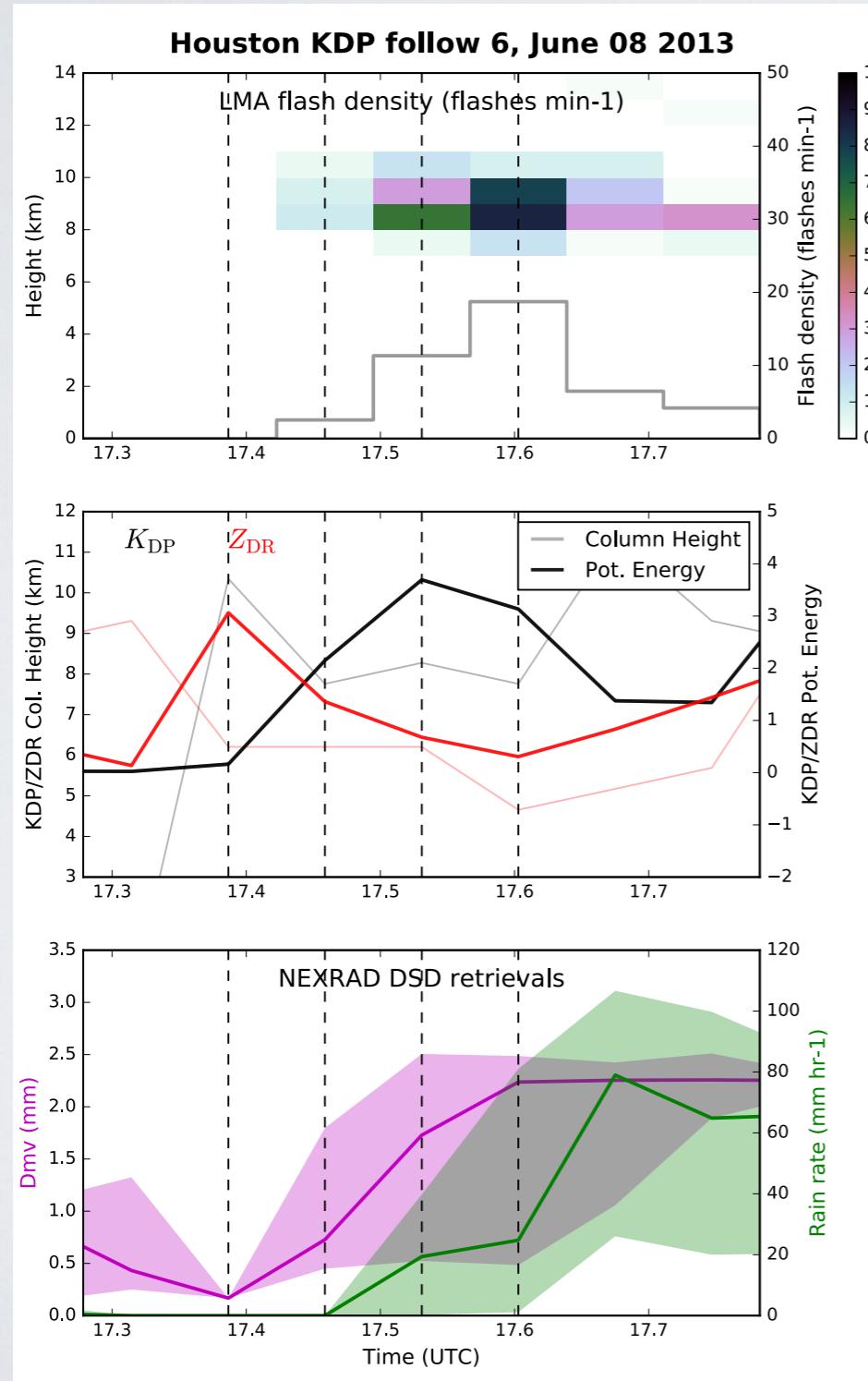
Column 6



Column 37



SUGGESTIVE CONTRASTS II



CONCLUSIONS

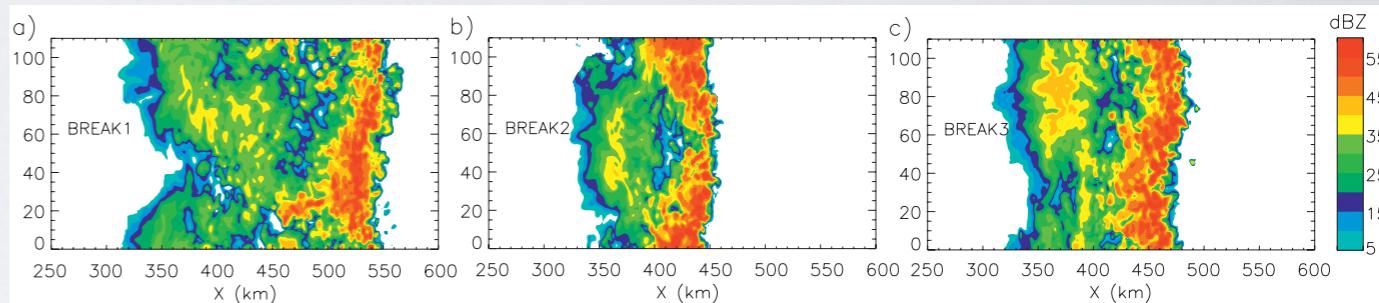
- Polarimetric radar observations provide crucial insights into deep convective microphysics
- Tracking KDP columns allows for comparison of evolution of individual updraft cells
- Some suggestion of possible aerosol effects on deep convective microphysics

A NEW (BAYESIAN) APPROACH TO MICROPHYSICAL PARAMETERIZATION SCHEMES

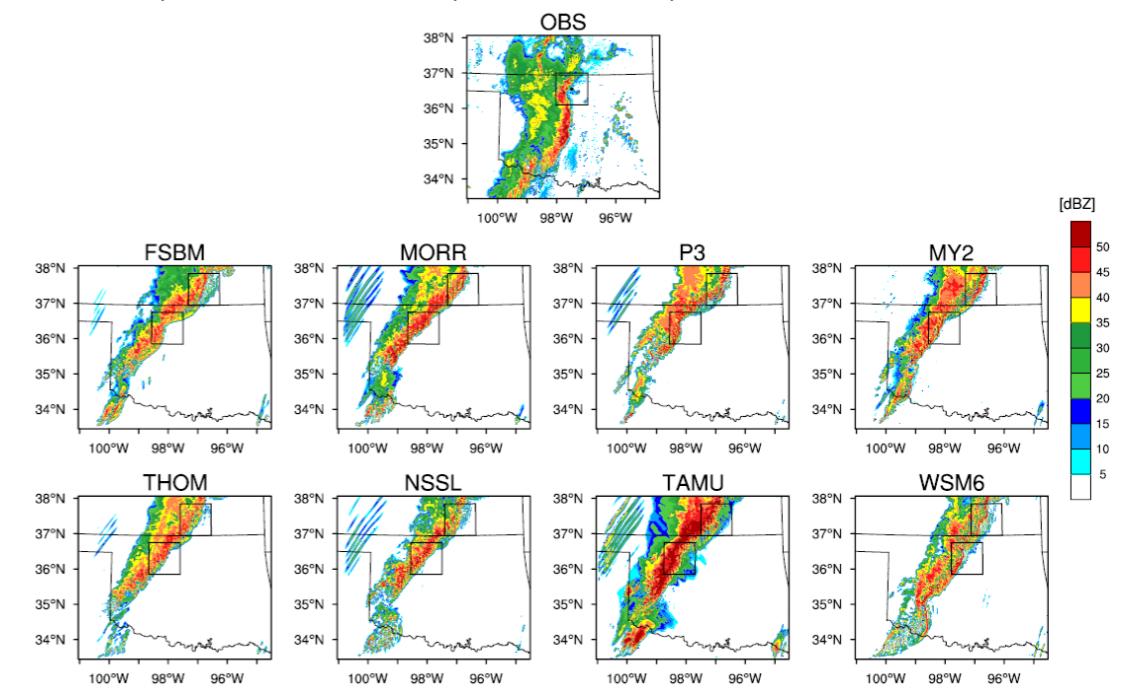
Marcus van Lier-Walqui (Columbia U. & NASA/GISS)
Matthew Kumjian, Charlotte Martinkus (Penn State U.)
Hugh Morrison (NCAR)
Olivier Prat (NC State University & NOAA)

MOTIVATION

- Microphysics schemes have error/uncertainty/approximations that result in:
 - QPF error
 - Poor ensemble spread
 - Limitations for use of models to understand microphysics



Split two sections for analysis of model data (black boxes)
Ze at 2km altitude
For observation, the time is 1000UTC; For simulations, the time is 0900UTC



TUNING KNOBS IN MICROPHYSICS SCHEMES



TUNING KNOBS



CAN BE DONE, BUT NOT EASY

- Posselt and Vukicevic 2010,
van Lier-Walqui et al 2012,
van Lier-Walqui et al 2014
- Can estimate parameter
PDFs with radar constraint
- Nonlinearities in response
to parameter perturbation
result in difficulties for
parameter estimation



WE'RE STILL JUST TURNING KNOBS



AND THERE ARE LOTS OF BLACK BOXES OUT THERE!



MICROPHYSICS OPTIONS IN WRF-ARW (18!)

Micro Physics Options (*mp_physics*)

Kessler Scheme	option 1	Kessler, E., 1969: On the distribution and continuity of water substance in atmospheric circulations. <i>Meteor. Monogr.</i>, 32, Amer. Meteor. Soc.
Lin et al. Scheme	option 2	Lin, Yuh-Lang, Richard D. Farley, and Harold D. Orville, 1983: Bulk Parameterization of the Snow Field in a Cloud Model. <i>J. Climate Appl. Met.</i>, 22, 1065–1092.
WRF Single-moment 3-class and 5-class Schemes	options 3 & 4	Hong, Song-You, Jimy Dudhia, and Shu-Hua Chen, 2004: A revised approach to ice microphysical processes for the bulk parameterization of clouds and precipitation. <i>Mon. Wea. Rev.</i>, 132, 103–120.
Eta (Ferrier) Scheme	option 5	NOAA, cited 2001: National Oceanic and Atmospheric Administration Changes to the NCEP Meso Eta Analysis and Forecast System: Increase in resolution, new cloud microphysics, modified precipitation assimilation, modified 3DVAR analysis. [Available online at http://www.emc.ncep.noaa.gov/mmb/mmbpll/eta12tpb/ .]
WRF Single-moment 6-class Scheme	option 6	Hong, S.-Y., and J.-O. J. Lim, 2006: The WRF single-moment 6-class microphysics scheme (WSM6). <i>J. Korean Meteor. Soc.</i>, 42, 129–151.
Goddard Scheme	option 7	Tao, Wei-Kuo, Joanne Simpson, Michael McCumber, 1989: An Ice–Water Saturation Adjustment. <i>Mon. Wea. Rev.</i>, 117, 231–235.
Thompson Scheme	option 8	Thompson, Gregory, Paul R. Field, Roy M. Rasmussen, William D. Hall, 2008: Explicit Forecasts of Winter Precipitation Using an Improved Bulk Microphysics Scheme. Part II: Implementation of a New Snow Parameterization. <i>Mon. Wea. Rev.</i>, 136, 5095–5115.
Milbrandt–Yau Double Moment Scheme	option 9	Milbrandt, J. A., and M. K. Yau, 2005: A multimoment bulk microphysics parameterization. Part I: Analysis of the role of the spectral shape parameter. <i>J. Atmos. Sci.</i>, 62, 3051–3064. Milbrandt, J. A., and M. K. Yau, 2005: A multimoment bulk microphysics parameterization. Part II: A proposed three-moment closure and scheme description. <i>J. Atmos. Sci.</i>, 62, 3065–3081.
Morrison 2-moment Scheme	option 10	Morrison, H., G. Thompson, V. Tatarskii, 2009: Impact of Cloud Microphysics on the Development of Trailing Stratiform Precipitation in a Simulated Squall Line: Comparison of One- and Two-Moment Schemes. <i>Mon. Wea. Rev.</i>, 137, 991–1007.

CAM V5.1 2-moment 5-class Scheme	option 11	Eaton, Brian. "User's Guide to the Community Atmosphere Model CAM-5.1." NCAR. URL http://www.cesm.ucar.edu/models/cesm1.0/cam (2011).
Stony-Brook University Scheme	option 13	Lin, Yanluan, and Brian A. Colle, 2011: A new bulk microphysical scheme that includes riming intensity and temperature-dependent ice characteristics. <i>Mon. Wea. Rev.</i>, 139, 1013–1035.
WRF Double Moment 5-class and 6-class Schemes	options 14 & 16	Lim, K.-S. S., and S.-Y. Hong, 2010: Development of an effective double-moment cloud microphysics scheme with prognostic cloud condensation nuclei (CCN) for weather and climate models. <i>Mon. Wea. Rev.</i>, 138, 1587–1612.
NSSL 2-moment Scheme and 2-moment Scheme with CCN Prediction	options 17 & 18	Mansell, E. R., C. L. Ziegler, and E. C. Bruning, 2010: Simulated electrification of a small thunderstorm with two-moment bulk microphysics. <i>J. Atmos. Sci.</i>, 67, 171–194.
NSSL 1-moment 7-class Scheme	option 19	This is a single-moment version of the NSSL 2-moment scheme (see above). No paper is available yet for this scheme.
NSSL 1-moment 6-class Scheme	option 21	Gilmore, Matthew S., Jerry M. Straka, and Erik N. Rasmussen, 2004: Precipitation uncertainty due to variations in precipitation particle parameters within a simple microphysics scheme. <i>Mon. Wea. Rev.</i>, 132, 2610–2627.
Aerosol-aware Thompson Scheme	option 28	Thompson, Gregory, and Trude Eidhammer, 2014: A study of aerosol impacts on clouds and precipitation development in a large winter cyclone. <i>J. Atmos. Sci.</i>, 71, 3636–3658.
HUJI SBM (Fast)	option 30	Khain, A., B. Lynn, and J. Dudhia, 2010: Aerosol effects on intensity of landfalling hurricanes as seen from simulations with the WRF model with spectral bin microphysics. <i>J. Atmos. Sci.</i>, 67, 365–384.
HUJI SBM (Full)	option 32	Khain, A., A. Pokrovsky, M. Pinsky, A. Seifert, and V. Phillips, 2004: Simulation of effects of atmospheric aerosols on deep turbulent convective clouds using a spectral microphysics mixed-phase cumulus cloud model. Part I: model description and possible applications. <i>J. Atmos. Sci.</i>, 61, 2963–2982.

Parametric AND Structural Uncertainties!!

NOBODY KNEW MICROPHYSICS COULD BE SO COMPLICATED!

- Nobody!
- How do we address parametric AND structural uncertainties?
 - Even if we perturb/estimate parameters in all available, existing schemes, how do we adequately weight individual schemes?
 - For ensemble prediction, how do we span the space between discrete choices of microphysics schemes?

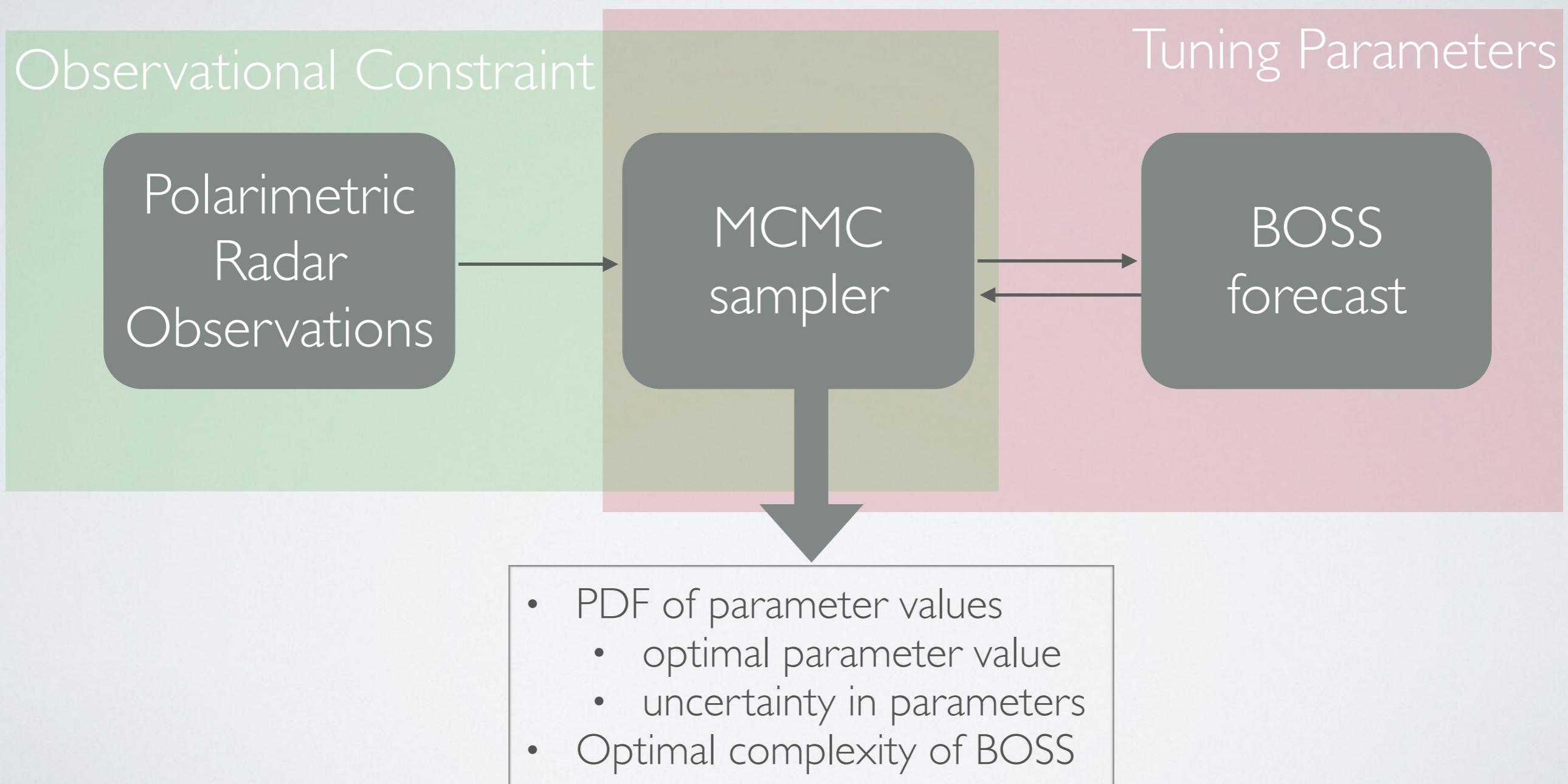
MICROPHYSICS SCHEME “WISH-LIST”

- Flexible DSD assumptions (no fixed functional form)
- Flexible process rate formulation (e.g. power series)
- Very few ad-hoc parameter choices and assumptions
- Complexity that can be added/subtracted as needed as required by **comparison to observations**

BOSS

- Bayesian (we treat uncertainties robustly)
- Observationally-constrained (scheme is informed by comparison to observations)
- Statistical-physical (we don't just want a statistical scheme, but we will use statistics)
- Scheme (liquid-only at this point)

BOSS, SIMPLIFIED



BOSS, MORE COMPLICATED

Obs and fwd Model

Polarimetric
Radar
Observations y

Error model
(obs, fwd obs)

Radar
forward
operator

BOSS
forecast

Comparison to obs,
prior belief

Calculate
“Likelihood”
of parameter values
 $P(y|x)$

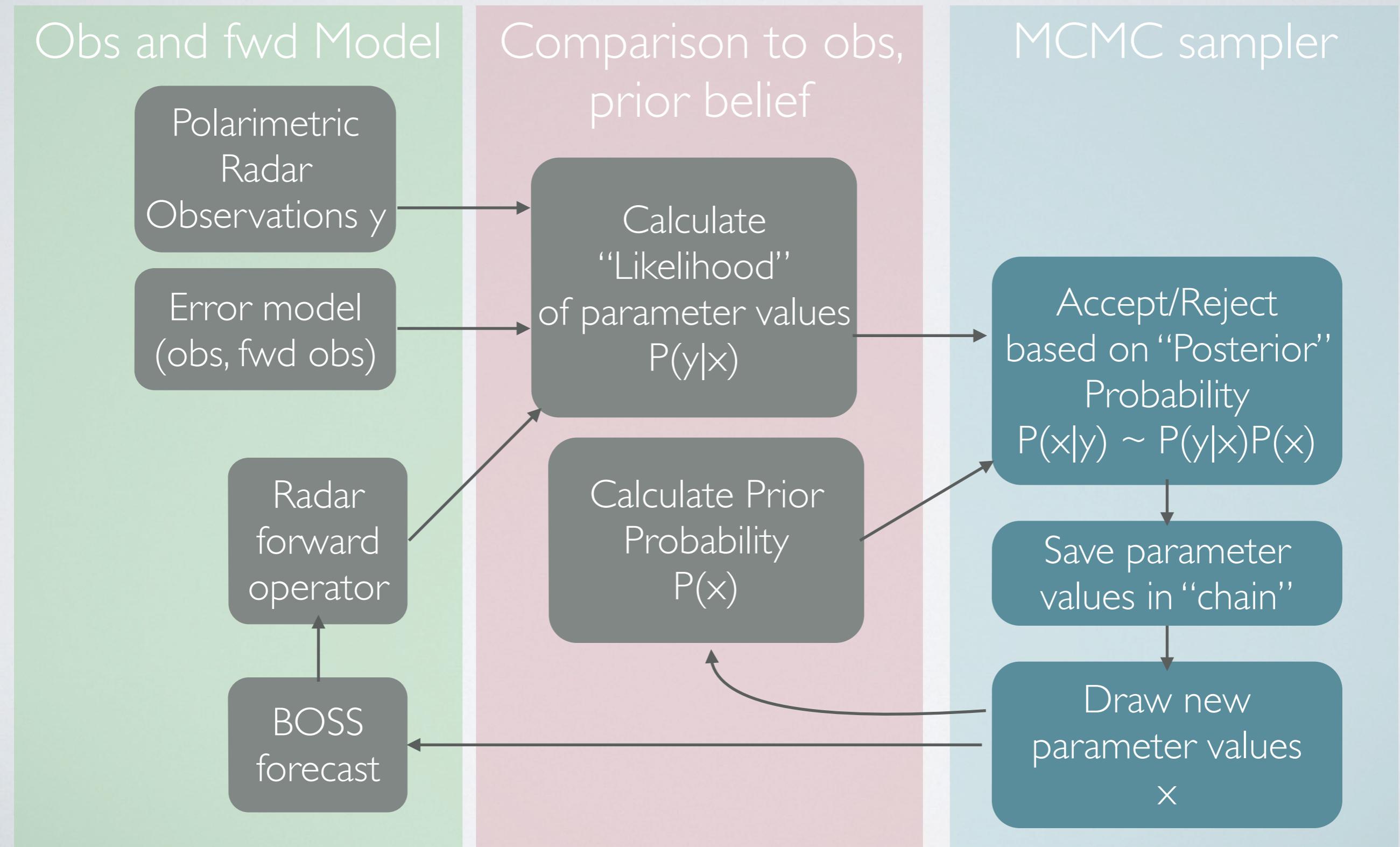
Calculate Prior
Probability
 $P(x)$

MCMC sampler

Accept/Reject
based on “Posterior”
Probability
 $P(x|y) \sim P(y|x)P(x)$

Save parameter
values in “chain”

Draw new
parameter values
 x



FORWARD OPERATOR CHALLENGES

- Typically, radar variables are calculated from a DSD, assuming some dependence on drop size, by integrating the DSD
- We have no DSD to integrate , only moments (any we choose, though!)

$$M_k \equiv \int_0^{\infty} D^k N(D) dD$$

- $\neg \backslash (\forall) \neg$
- We must build a polarimetric forward operator that is based on prognostic moments
 - this is hard
 - really hard

A MOMENT-BASED POLARIMETRIC FWD OPERATOR

- Mine bin simulations (18000+) to extract relationships between DSD moments and polarimetric observations
- Do the same for disdrometer data (5000+)
- Estimate forward simulator uncertainty based on spread in radar variables for a given prognostic moment combination

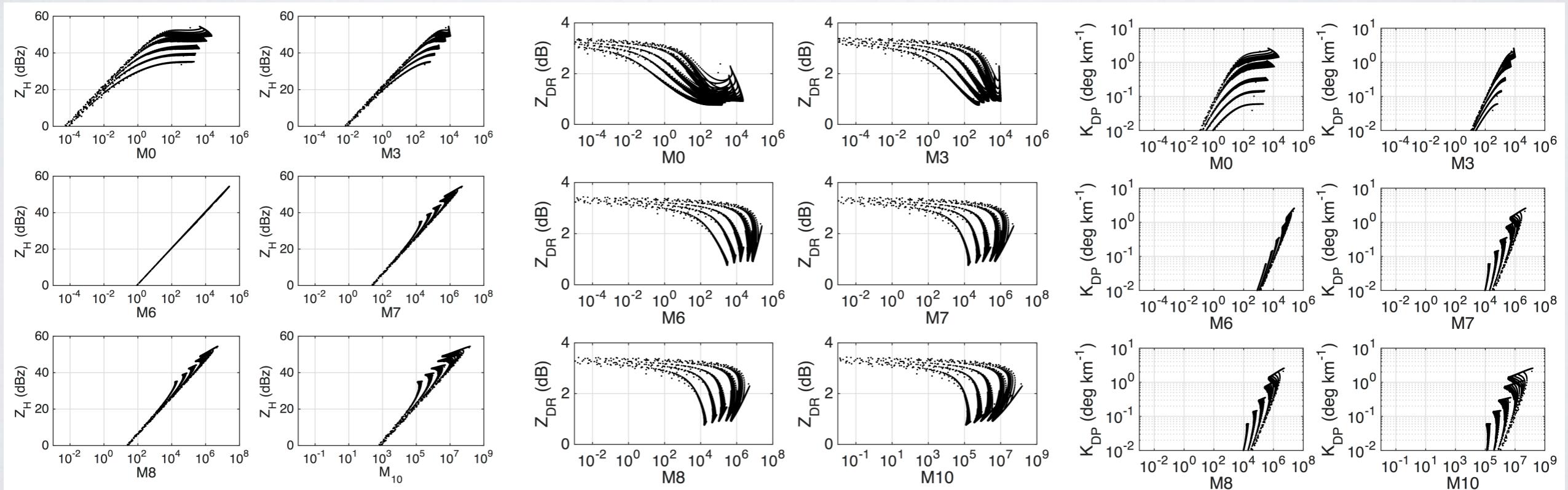
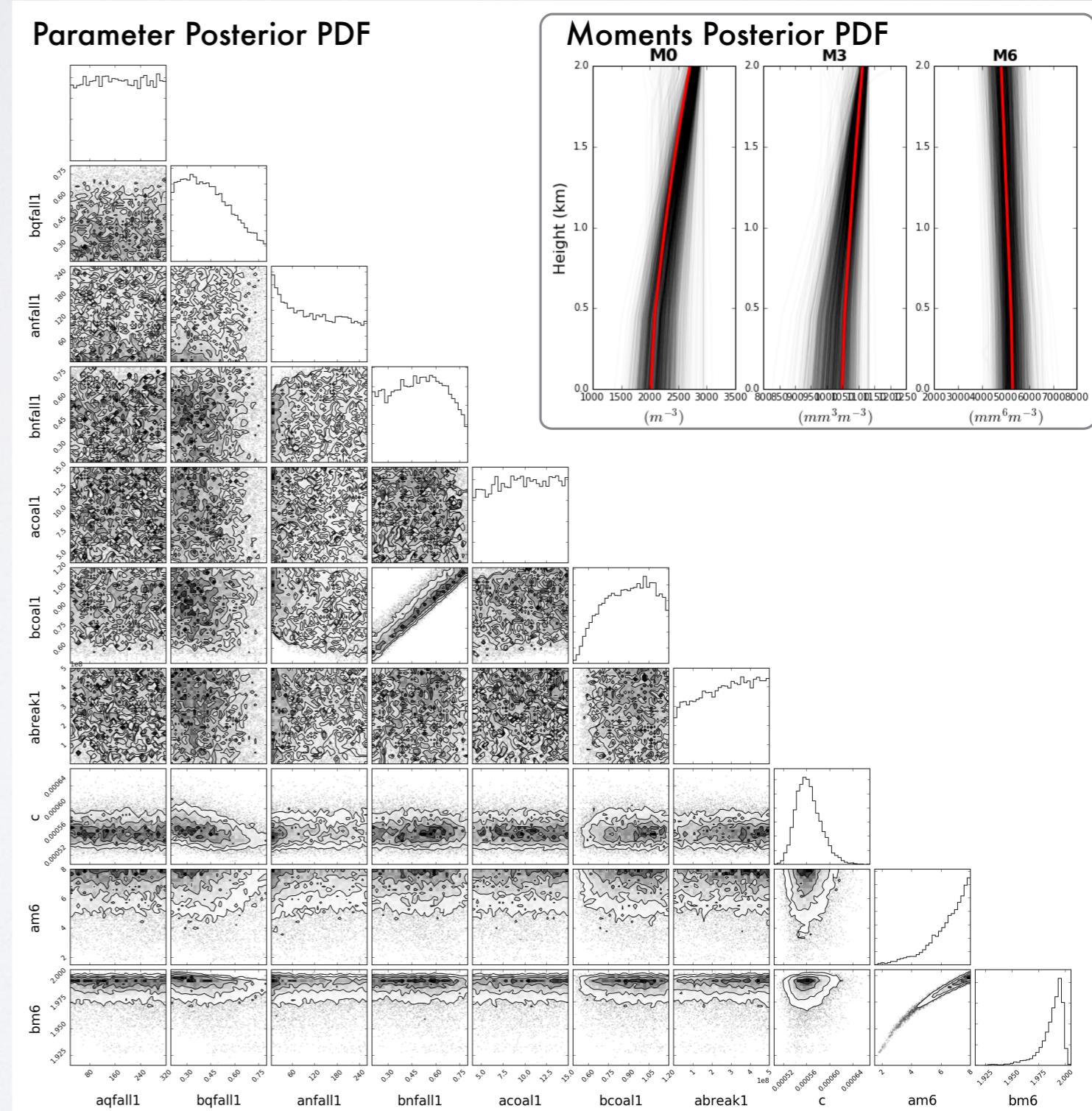


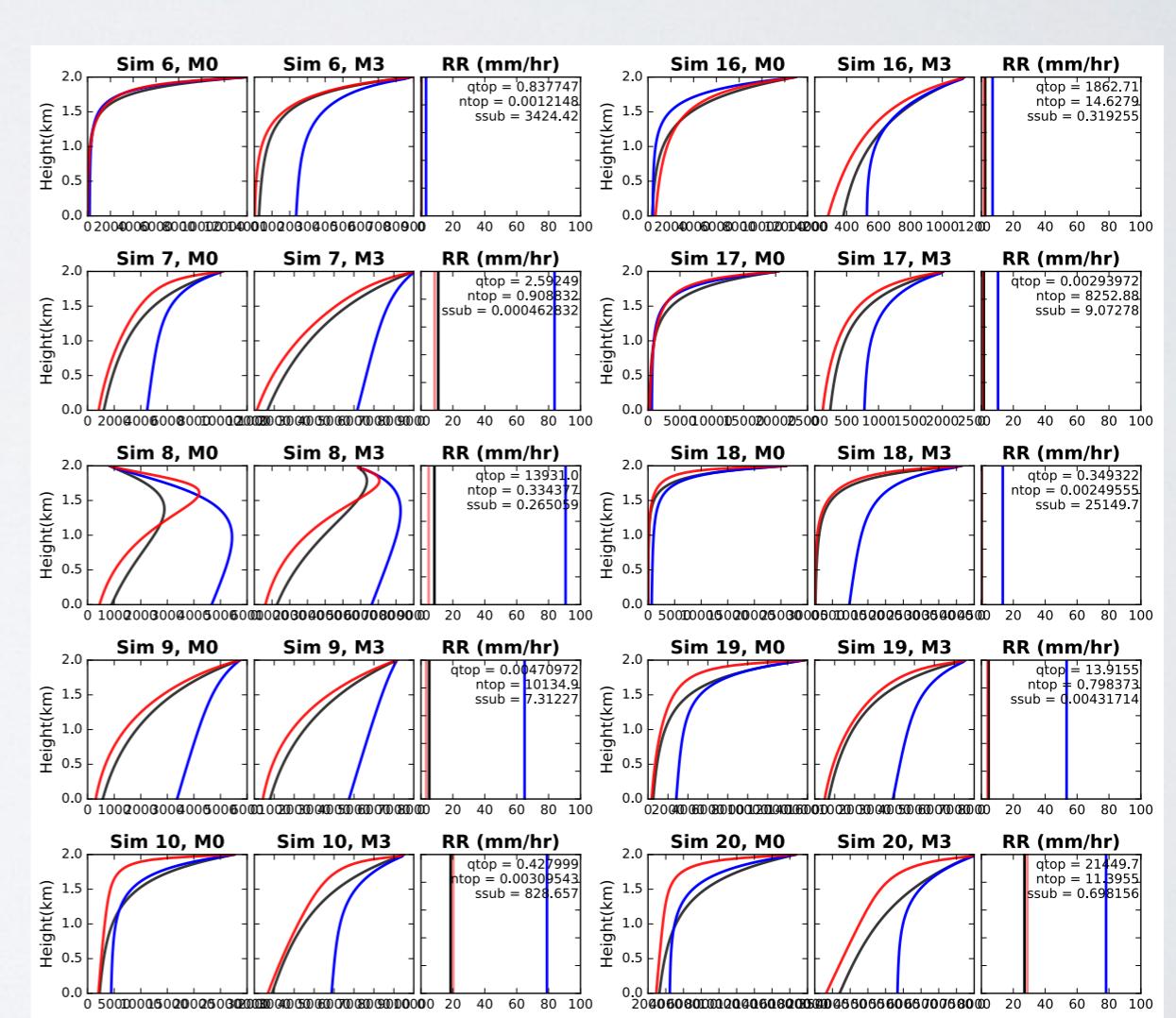
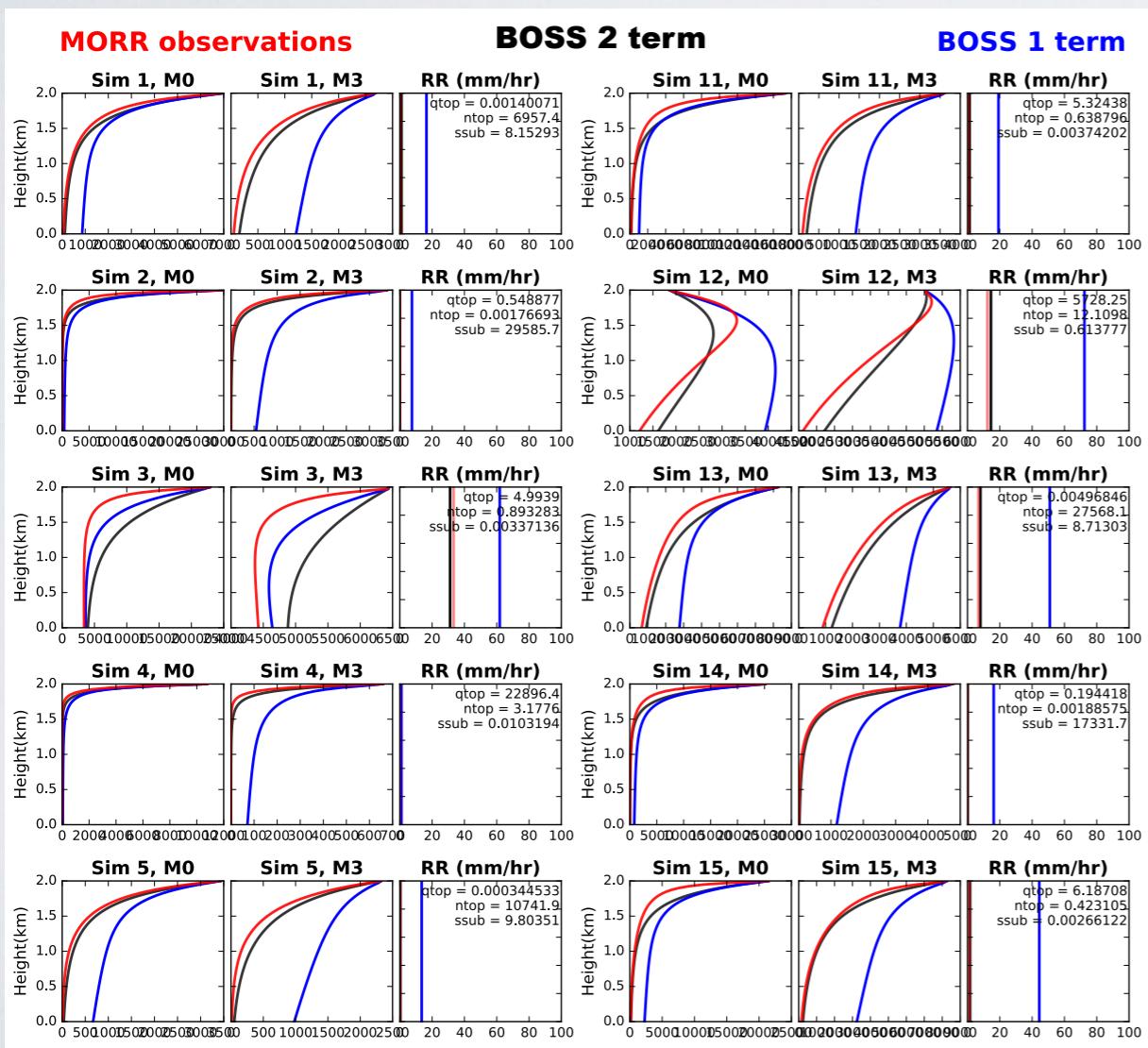
Fig. 6: Scatterplots of Z_H (left, in dBz), Z_{DR} (middle, in dB) and K_{DP} (right, in deg km⁻¹ in log scale) as a function of different moments of the DSD calculated from bin model simulations of evolving rain shafts with varying rainfall intensities (values of the moments in log scale, in units of mm^k m⁻³, where k indicates the kth moment).

WHAT DO WE GET OUT OF BOSS?

- Estimate of optimal parameter values
- Estimate of parameter uncertainty
- Forecast uncertainty due to microphysics uncertainty
- Relationships/sensitivity between observations, parameter values, and simulated microphysical processes (not shown)



WE CAN USE LOT OF OBS FOR MANY MANY CASES



CONCLUSIONS

- We have created a new microphysics scheme that:
 - eschews assumptions about DSD and functional form of process rates
 - Allows for constraint and estimation of both parametric and structural uncertainty using observations
- Ongoing challenges:
 - Develop radar forward operator
 - Assemble appropriate observations
 - Develop MCMC sampler to automatically choose number of power-series terms